California Environmental Protection Agency

Air Resources Board

Detailed California-Modified GREET Pathway for Cellulosic Ethanol from Farmed Trees by Fermentation

Stationary Source Division

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The Staff of the Air Resources Board developed this preliminary draft version as part of the Low Carbon Fuel Standard Regulatory Process

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These comments will be compiled, reviewed, and posted to the LCFS website in a timely manner

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SUMMARY

CA-GREET Model Pathway for Farmed trees Ethanol

A Well-To-Tank (WTT) Life Cycle Analysis of a fuel (or blending component of fuel) pathway includes all steps from feedstock production to final finished product. Tank-To-Wheel (TTW) analysis includes actual combustion of fuel in a motor vehicle for motive power. Together WTT and TTW analysis are combined together to provide a total Well-To-Wheel (WTW) analysis.

A Life Cycle Analysis Model called the **G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation (GREET)[1] developed by Argonne National Laboratory has been used to calculate the energy use and Greenhouse gas (GHG) emissions and consequent GHG emissions generated during the entire process from farmed trees growing, farmed trees processing to ethanol and transportation to a blending station. The model however, was modified by TIAX under contract to the California Energy Commission during the AB 1007 process[2]. Changes were restricted to mostly input factors (electricity generation factors, crude transportation distances, etc.) with no changes in methodology inherent in the original GREET model. This California-modified GREET model formed the basis for all the fuel pathways published by staff in mid-2008. Subsequent to this, the Argonne Model was updated in September 2008. To reflect the update and to incorporate other changes, staff contracted with Life Cycle Associates to update the CA-GREET model. This updated California modified GREET model (v1.8b) (released December 2008) forms the basis of this document. It has been used to calculate the energy use and greenhouse gas (GHG) emissions associated with a WTW analysis of the farmed trees to ethanol pathway.

Note: Any impacts from Land Use Change have not been analyzed for this document. Any updates from Land Use Change analysis will need to be addressed for this pathway.

This document details the energy and inputs required to produce ethanol from farmed trees outside of California and transport the ethanol by rail to blending terminals in California for blending with CARBOB. The small diameter farmed trees could be poplar, pine, eucalyptus, or genetically engineered trees. Well-to-tank greenhouse gas emissions are also calculated based on the energy results and provided in this document. Figure 1 below outlines the discrete components that comprise the farmed trees ethanol pathway, from trees farming to ethanol transport and distribution. Note that anhydrous ethanol (which is distilled ethanol >99.6% purity) has been used as the basis for all calculations in this document. Please refer to the CaRFG document on the LCFS website which includes calculations for the use of ethanol with a denaturant.

Several general descriptions and clarification of terminology used throughout this document are:

[1] http://www.transportation.anl.gov/software/GREET/
[2] http://www.energy.ca.gov/ab1007/

- CA-GREET employs a recursive methodology to calculate energy consumption and emissions. To calculate WTT energy and emissions, the values being calculated are often utilized in the calculation. For example, crude oil is used as a process fuel to recover crude oil. The total crude oil recovery energy consumption includes the direct crude oil consumption and the energy associated with crude recovery (which is the value being calculated).
- Btu/mmBtu is the energy input necessary in Btu to produce one million Btu of a finished (or intermediate) product. This description is used consistently in CA-GREET for all energy calculations.
- gCO_2e/MJ provides the total greenhouse gas emissions on a CO_2 equivalent basis per unit of energy (MJ) for a given fuel. Methane (CH_4) and nitrous oxide (N_2O) are converted to a CO_2 equivalent basis using IPCC (Intergovernmental Panel on Climate Change) global warming potential values and included in the total.
- CA-GREET assumes that VOC and CO are converted to CO_2 in the atmosphere and includes these pollutants in the total CO_2 value using ratios of the appropriate molecular weights.
- Process Efficiency for any step in CA-GREET is defined as:

  Efficiency = energy output / (energy output + energy consumed)

- Note that rounding of values has not been performed in several tables in this document. This is to allow stakeholders executing runs with the CA-GREET model to compare actual output values from the CA-modified model with values in this document.

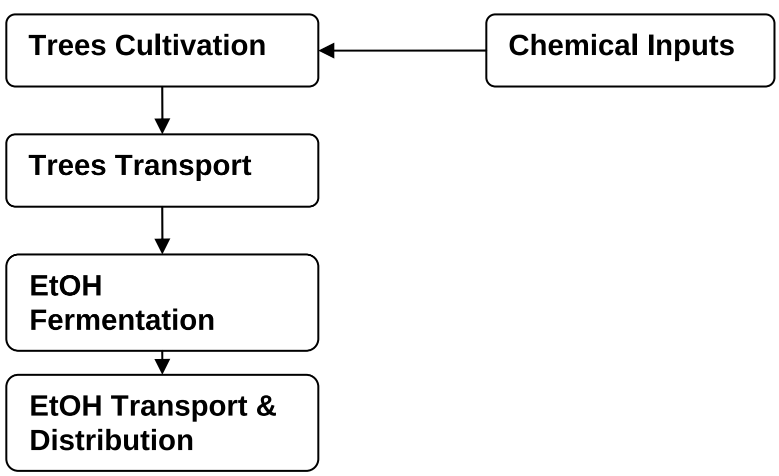

Figure 1. WTT Components for Ethanol Transported to California

Table A below summarizes the fuel cycle energy inputs by stage (Btu/mmBtu) and Table B summarizes the major GHG emission categories and intensities (gCO_2e/MJ). The Tables present energy and emission results relative to the energy content (LHV) of anhydrous ethanol. Complete details of all energy inputs and GHG emissions are provided in Appendix A. A list of all inputs is provided in Appendix B. Due to negative values resulting from co-product credits, all % have not been calculated.

Table A. Energy Use by Stage for Farmed Trees to Ethanol Pathway

Farmed Trees ethanol WTT Components	Ethanol from farmed trees by Fermentation	
	Energy* (Btu/mmBtu)	% Energy Contribution
Farmed Trees Cultivation	44,136	
Energy Inputs for Ag Chemicals	6,409	
Farmed Trees Transportation	28,907	
Ethanol Production	1,453,295	
Ethanol T&D	30,132	
Co-gen Credit	-107,120	
Storage	0	
Total well-to-tank	**1,455,759**	**59.27%**
Neat Ethanol	1,000,000	40.73%
Total tank-to-wheel	**1,000,000**	**40.73%**
Total well-to-wheel	**2,455,759**	100%

Table B. GHG Emissions Summary for Farmed Trees to Ethanol Pathway

Farmed Trees Ethanol Fuel Cycle Components	GHGs	% Emission Contribution
Farmed Trees Cultivation	3.24	
Ethanol Production	109.50	
Ag Chemicals Production and Use (inclusive of N_2O release from fertilizer)	1.1	
Farmed Trees Transportation	2.2	
CO2 credit from burning of Lignin in Trees	-106.90	
Ethanol T&D	2.30	
Co-Gen Credit	-6.06	
Total well-to-tank	**5.38**	**100%**
Total tank to wheel	**0**	0
Total well-to-wheel	**5.38**	**100%**

WTT Details

This section provides a breakdown of the various energy and related GHG emissions for all the various components of the ethanol pathway detailed in Figure 1. Complete details including calculations, equations, etc. are provided in Appendix A.

FARMED TREES CULTIVATION

Table C provides a breakdown of energy input from each fuel type used in trees farming activities. Table D provides information on GHG emissions related to the use of energy for trees farming. . Additional details are provided in Appendix A.

Table C. Total Energy Input by Fuel for Trees Cultivation

Fuel Type	Total Energy (Btu/Btu)
Diesel fuel	39,702
Electricity	4,434
Total Energy for trees farming for anhydrous ethanol (Btu/mmBtu)	**44,136**

Table D. GHG Emissions from Farmed Trees Cultivation

Farmed Trees Ethanol Production	By Fermentation
Emission Species	GHG (gCO_2e/mmBtu)
VOC	11.7
CO	22.2
CH_4	111
N_2O	14.2
CO_2	3,261
Total GHG (gCO_2e/mmBtu)	3,420
Total GHG (gCO_2e/MJ) (Anhydrous)	**3.24**

CHEMICAL INPUTS FOR AGRICULTURAL CHEMICALS

Table E provides details the energy inputs required to produce various chemicals used in agricultural operations related to trees farming. Table F provides details of the associated GHG emissions related to the production of these chemicals.

Table E. Energy Inputs for Agricultural Chemicals for Trees Farming

Chemical Type	**Energy Use (Btu/dry ton)**	**Anhydrous ethanol Energy Use, (Btu/mmBtu)**
Nitrogen Fertilizer	32,125	4,676
Phosphate Fertilizer	2,444	356
Potash	2,612	380
Herbicide (average)	5,016	730
Insecticide (average)	606	88.2
Total		**6,409**

Table F.. Total GHG Emissions from Agricultural Chemical Use

GHGs	**Fertilizers**	**Herbicide**	**Pesticide**	**N2O from fertilizer use**	**Total**
gCO_2e/MJ	0.36	0.06	0.01	**0.6**	**1.1**

FARMED TREES TRANSPORT

Table G details the energy inputs required to transport farmed trees from the farm to the ethanol production plant. Table H provides details of the associated GHG emissions related to transportation of farmed trees from the farm to the ethanol plant.

Table G. Farmed Trees Transport Energy

Transport Mode	Energy Consumption
Trees Field to Ethanol Plant Heavy Duty Truck (Btu/dry ton)	198,591
Total in (Btu/mmBtu)	**28,907**

Table H. Farmed Trees Transport – Total GHG Emissions

Transport Mode	GHG Emissions (gCO_2e/MJ)
Field to Ethanol Plant by Heavy Duty Truck	2.2
Total	**2.2**

ETHANOL PRODUCTION

Table I details the energy inputs required to produce ethanol from farmed trees by fermentation. Table J provides details of the associated GHG emissions related to production of ethanol. It includes the impacts of burning the lignin from the trees as energy for production of ethanol.

Table I. Energy Use for Ethanol Production by Fermentation

Fuel Type	Total Energy
Diesel (Btu/gal)	415
Direct use from farmed tree (Btu/gal)	110,458
Total energy input for ethanol production (Btu/gal)	110,874
Total energy input for ethanol production (converted to Btu/mmBtu)	1,453,295

Table J. GHG Emissions for Ethanol Production by Fermentation

GHG Species	g CO_2e/mmBtu	g CO_2e/MJ
VOC	19.1	
CO	135.9	
CH_4	289	
N_2O	2041.1	
CO_2	113,042	
Total GHGs (gCO_2e/mmBtu)	115,527	**109.5**
CO_2 credit from direct use of tree burning as process fuel	(-112,808)	**(-106.9)**
Total GHGs	**2,719**	**2.6**

ETHANOL TRANSPORT AND DISTRIBUTION

Transport from the ethanol plant to the bulk terminal or storage facility is accomplished primarily by rail (with short truck delivery to terminal or storage facility). The local distribution step involves transporting ethanol to a gasoline blending terminal where it is blended with gasoline to produce RFG. Ethanol is transported by truck to the blending terminal. Table L details the energy inputs required to transport ethanol. Table M provides details of the associated GHG emissions related to ethanol transport and distribution.

Table K. Energy Use for Ethanol Transport and Distribution (T&D)

Transport Mode	Btu/mmBtu
Transportation by Rail	27,512
Distribution by Truck	2,620
T&D Total (Btu/mmBtu Anhydrous)	**30,132**

Table L. GHG Emissions Related to Ethanol Transport

Transport Mode	CH_4	N_2O	CO_2e	GHG gCO_2e/mmBtu
Transported by Rail	2.6	0.05	2,096	2,189
Distributed by Heavy Duty Truck	0.31	0.006	249	249
Total (gCO_2e/mmBtu)				**2,439**
Total (gCO_2e/MJ)				**2.3**

ENERGY AND GREENHOUSE GASES CREDITS

In cellulosic ethanol plants, cellulose in the trees is converted into ethanol through enzymatic process. The lignin portion of the trees can be burned in ethanol plants to provide needed steam. Co-generation systems can be employed to generate both steam and electricity from lignin. Some amount of extra electricity can be generated in cellulosic plants and be exported to the electric grid. U. S. average electric mix is used in the calculations. Table N provides a summary of energy credits generated by the co-generation electricity. Complete details of the calculation are provided in Appendix A. GHG emission credits corresponding to the energy credits are provided in Table O.

Table M. Co-Generation Electricity Credits from Farmed Trees Ethanol Plants

	Energy Credit (Btu/gal)	**Energy Credit (Btu/mmBtu)**
Total generated electricity credit for farmed trees ethanol production	-8,172	**-107,120**

Table N. GHG Emission Credits from Co-generation

Emissions	**g/gal**
CH_4	-12.7
N_2O	-0.1
CO_2	-6,051
Converted to GHG (gCO_2e/mmBtu)	6,388
Converted to GHG (gCO_2e/MJ)	**-6.06**

TTW DETAILS

Anhydrous ethanol is considered as not being used directly as a fuel in California. Hence TTW emissions from anhydrous ethanol are not considered here. From a CO_2 perspective, since atmospheric CO_2 was fixed by the plant during its growth, CO_2 release from combustion is considered GHG neutral for Farmed Trees ethanol.

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APPENDIX A

SECTION 1. FARMED TREES FARMING

1.1 Energy Use for Farmed Trees Cultivation

This section presents the direct farming energy inputs for trees cultivation. For trees cultivation, the CA-GREET model calculates energy and emissions based on the quantity of fuel (Btu) and chemicals used per quantity of product (dry ton of farmed trees), rather than using energy efficiencies, as the petroleum pathways do in CA-GREET. The total input energy per dry ton of farmed trees is 234,770 (CA-GREET default) with the mix of fuel types shown in Table 1.01. The trees farming energy input was shown in the original GREET 1.5[3] .

Table 1.01. Primary Energy Inputs by Fuel/Energy Input Type for Tree Farm Operations

Fuel Type	Fuel Share	Formula	Primary Energy Input (Btu/dry ton)
Diesel fuel	94.3%	94.3%*234,770	221,388
Electricity	5.7%	5.7%*234,770	13,382
Direct Energy Consumption for Farmed Trees Cultivation (Btu/dry ton)			**234,770**

The energy inputs are direct inputs and not total energy required. CA-GREET accounts for the 'upstream' energy associated with fuels by multiplying with appropriate factors which are shown in Table 1.02. Actual values used to calculate total energy in Table 1.02 are shown in Table 1.03. Table 1.04 provides additional details for values used in Table 1.03.

Table 1.02 Calculating Total Energy Input by Fuel for Farmed Trees Cultivation

Fuel Type	Formula	Total Energy
Diesel fuel	$A*[1+((B*C)+D)]/10^6$	272,740
Electricity	$E*(F+G)/10^6$	30,460
Total Energy for Trees Farming (Btu/dry ton)		303,200
Total Energy for Trees Farming (Btu/mmBtu)		**44,136**

Note: Anhydrous ethanol is "neat" fuel, typically 99.6% pure ethanol. The energy use for anhydrous ethanol is calculated from:
(Energy trees farming (Btu/dry ton) / (Ethanol Yield (gal/dry ton) * LHV of Anhydrous Ethanol (Btu/gal)))*10^6

Where:
LHV of anhydrous ethanol is 76,330 Btu/gal.
Ethanol yields for trees ethanol are assumed to be 90 gal/dry ton as CA-GREET default.

(303,200 (Btu/dry ton) / (90 (gal/dry ton)76,330 (Btu/gal))) x 10^6 = **44,136** Btu/mmBtu

[3] Wang, et al. (Aug 1999). "Transportation Fuel-Cycle Model ". Argonne, IL, prepared by Center for Transportation Research, Argonne National Laboratory – section 4, p.66

Table 1.03 Values Used in Table 1.02

Factor	Description	Value	Reference
A	Direct Diesel input	221,388 Btu/dry ton	calculated in Table 1.01
B	Crude energy	105,677 Btu/mmBtu	CA-GREET calculated – Cell B183 *Petroleum* tab
C	Diesel loss factor	1.0	CA-GREET default value
D	Conventional Diesel energy	126,272 Btu/mmBtu	CA-GREET calculated - Cell K183 *Petroleum* tab
E	Direct electricity input	13,382 Btu/dry ton	calculated in Table 1.01
F	Stationary electricity feedstock production	103,008 Btu/mmBtu	CA-GREET calculated - Cell B84 *Electricity* tab
G	Stationary electricity fuel consumption	2,173,222 Btu/mmBtu	CA-GREET calculated - Cell C84 *Electricity* tab

The factors listed in Table 1.03 are derived from the energy contributions of all other fuels that were used to produce ethanol. Those fuels are shown in Table 1.04 below, in two components: WTT energy (E) and Specific Energy (S) for each fuel type.

Table 1.04 Energy Consumption in the WTT Process and Specific Energy (from Upstream Sources)

	WTT energy (Btu input/mmBtu product)	**S: Specific Energy (Btu input/Btu product)**
Crude CR	WTT CR = 105,677 (CA-GREET calculated)	S CR = 1+WTT CR/10^6 = 1.028
B	WTT Crude = WTT CR*LF T&D + WTT Crude T&D + WTT Crude Storage= 94,335*1 +11,341 + 0 = 105,677	LF T&D =Loss Factor for Transport and Distribution = 1.00 (CA-GREET default) WTT Crude T&D= 11,341 (CA-GREET calculated) WTT Crude Storage = 0 (CA-GREET default)
D	WTT Diesel = 126,272 (CA-GREET calculated)	S Diesel = 1+ (WTT Crude*Loss Factor Diesel+ WTT Diesel)/ 10^6 = 1.232. Loss Factor for diesel = 1 (CA-GREET calculation: cell B170 – *T&D* tab).
Electricity		S Electricity = (WTT feedstock +WTT fuel)/ 10^6 = 2.276 (CA-GREET calculation: cell R170 – *T&D* tab).
F	WTT feedstock production = 103,008 CA-GREET calculated)	
G	WTT feedstock consumption= 2,173,222 (CA-GREET calculated)	

Note:
WTT CR: WTT energy for Crude Oil Recovery, of self use of crude oil at the well, not includes T&D.
WTT Crude Storage: WTT energy of Crude storage

1.2 GHG Emissions from Farmed Trees Cultivation

CA-GREET calculates carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions for each component of the pathway and uses IPCC Global Warming Potentials (GWPs) to calculate CO_2 equivalent values for methane and nitrous oxide (see Table 1.05). For VOC and CO, CA-GREET uses a carbon ratio to calculate CO_2 equivalent values which are detailed in a note below Table 1.05. These are based on the oxidation of CO and VOC to CO_2 in the atmosphere. The GHG emissions resulting from fuel use in the EtOH Production Process is shown in Table 1.06. All emission factors listed are CA-GREET default values.

Table 1.05 Global Warming Potentials for Gases

GHG Species	GWP (relative to CO_2)
CO_2	1
CH_4	25
N_2O	298

Note: values from mmBtu to MJ have been calculated using 1 mmBtu = (1/1055) MJ
Carbon ration of VOC = 0.85 grams CO_2/MJ = grams VOC*(0.85)*(44/12) = 3.1
Carbon ratio of CO = 0.43 grams CO_2/MJ = grams CO/mmBtu*(0.43)*(44/12) = 1.6
where 44 and 12 are molecular weights of CO_2 and C, respectively.

Table 1.06: CO_2 Emission Factors from Upstream Sources

	EF= emissions factors for WTT CO_2 (gCO_2/mmBtu fuel output)	SE: Specific Emission (gCO_2e/mmBtu fuel output)
Crude CR	EF CR = 6,406	SE CR = (1+EF CR)/10^6
Crude	EF Crude = EF CR *LF T&D + EF Crude T&D + EF Crude Storage + (VOC and CO conversion) = 6406*1 +871 +0 + (6.5*.85/.27) + (27.5*.43/.27) = 7,341	
Conventional Diesel	EF Diesel = 8,834	SE Diesel = [1+(EFCrude*Loss Factor Diesel+EF Diesel)]/10^6
Electricity	EF feedstock = 7,135, EF fuel = 121,444	SE Electricity = (EF feedstock +EF fuel)/10^6

Note:
CR: Crude Recovery
LF: Loss Factor
EF: Emission Factor
NG: Natural Gas

The greenhouse gas emissions for farm energy use are determined separately for CO_2, CH_4 and N_2O in CA-GREET using the direct energy inputs presented in Section 1.1 (Btu/dry ton) and the combustion and upstream emissions for the energy input. CA-GREET calculates the emissions for each fossil fuel input by multiplying fuel input (Btu/dry ton) by the total emissions from combustion, crude production and fuel production. The electricity emissions are calculated by multiplying the electricity input (Btu/dry ton) by the total (feedstock plus fuel) emissions associated with the chosen electricity mix (from the Electricity Tab in CA-GREET model). Table 1.07 below shows formulas and calculated values by fuel type for trees farming CO_2 emissions. Formulas and values for CH_4 and N_2O are not shown, but use the same formula structure. Table 1.08 provides values for parameters used in the formulas in Table 1.07.

Table 1.07. CA-GREET Calculations for CO_2 Emissions from Trees Cultivation (from Upstream Sources)

Fuel	Formula	CO_2 Emissions (g/dry ton)
Diesel	[(A)*[(B)*(C) + (D)*(E)+(F)*(G)+ (H)*(I)+(J)*(K)+(L)]]/10^6	20,679
Electricity	[(M)*[(N)+(O)]]/10^6	1,721
Total CO_2 emissions (g/ton)		**22,400**
Conversion to total CO_2 emissions (g/mmBtu)		**3,261**
Conversion to (g/MJ)		**3.1**

Note: The calculations for CH_4 and N_2O are analogous. Relevant parameters here are calculated values in CA-GREET, except for technology shares, which are direct inputs.
To convert (g/dry ton) to (g/mmBtu): (g/dry ton)/(Ethanol Yield (gal/dry ton) * LHV of Anhydrous Ethanol (Btu/gal))*10^6.
Where LHV of ethanol is 76,330 Btu/gal and ethanol yield is assumed to be 90 gal/dry ton

Table 1.08. CA-GREET Calculations for CO_2 Emissions Associated with Farmed Trees Cultivation

Fuel	Relevant Parameters*	Reference
A	Diesel input = 221,388 Btu/dry ton	Table 1.01
B	% Fuel share diesel boiler = 0%	CA-GREET default
C	Boiler CO_2 emissions = 78,167 g/mmBtu	CA-GREET default
D	% Fuel share diesel stationary engine = 20%	CA-GREET default
E	IC Engine CO_2 Emissions =77,401 g/mmBtu	CA-GREET default
F	% Fuel share diesel turbine = 0%	CA-GREET default
G	Turbine CO_2 emissions 78,179 g/mmBtu	CA-GREET default
H	% Fuel share diesel tractor = 80%	CA-GREET default
I	Tractor CO_2 emissions = 77,204 g/mmBtu	CA-GREET default
J	Crude production CO_2 emissions = 7,341 g/mmBtu	Table 1.06
K	Diesel loss factor = 1.0	CA-GREET default
L	Diesel production CO_2 emissions = 8,834 g/mmBtu	Table 1.06
M	Electricity input = 13,382 Btu/dry ton	Table 1.01
N	Electricity feedstock CO_2 emissions = 7,135 g/mmBtu	Table 1.06
O	Electricity fuel CO_2 emissions = 121,444 g/mmBtu	Table 1.06

Note: The calculations for CH4 and N2O are in similar ways but with different values of emission factors.
*Relevant parameters here are calculated values in CA-GREET, except for technology shares, which are direct inputs.

VOC, CO, CH_4, and N_2O emissions are calculated with the same formulas, energy input, and loss factors as CO_2 emissions calculations shown in Table 1.07, but with different VOC, CO, CH_4, and N_2O emission factors. Table 1.09 shows the results of the calculations of VOC, CO, CH_4, and N_2O in (g/dry ton) then converted to g/mmBtu.   CA-GREET has an exogenous credit for land use change emission for trees cultivation soil CO_2 sequestration. For this document, this credit has not been considered and will need to be reviewed in the future.

Table 1.09 GHG Emissions from Trees Cultivation

Emission Species	**Emissions[1] (g/dry ton)**	**GHG (g/mmBtu)**	**GHG (gCO_2e/mmBtu)**
VOC	25.3	3.7	11.6
CO	96	14	22.2
CH_4	30.5	4.43	111
N_2O	0.3	0.05	14.2
CO_2	22,400	3,261	3,261
Total GHG (gCO_2e/mmBtu)			3,420
Total GHG (gCO_2e/MJ)			**3.24**

Note: [1]Emissions in grams of gaseous species per dry ton. To convert all VOC, CO, CH_4 and N_2O (g/dry ton) to (g/mmBtu) = (g/dry ton)/(Ethanol Yield (gal/dry ton) / LHV of Anhydrous Ethanol (Btu/gal))*10^6

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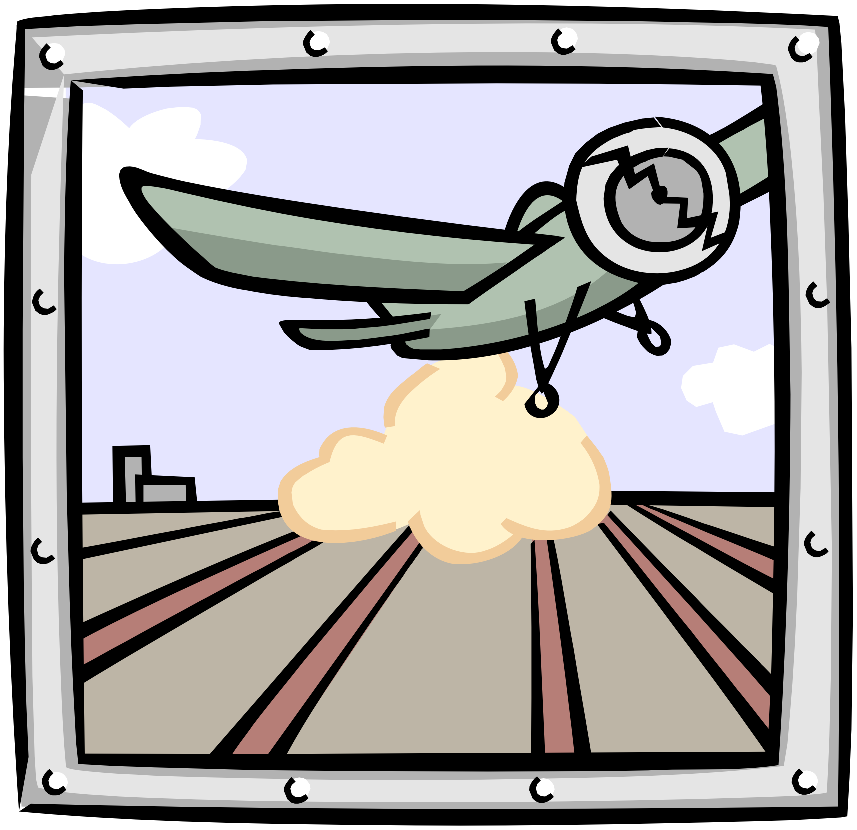
SECTION 2. CHEMICAL INPUTS FOR AGRICULTURAL CHEMICALS



2.1 Energy Calculations for Production of Chemical Inputs

Chemical inputs, including fertilizer, herbicide and insecticide, are input on a g-nutrient/dry ton (fertilizer) or g-product/dry ton (herbicide and pesticide) basis. Table 2.01 below presents the CA-GREET chemical inputs per dry ton of farmed trees, the total energy required to produce the chemical product and the calculated upstream energy required to produce a dry ton of farmed trees using these inputs. Both chemical input values and product energy values are CA-GREET defaults.

Table 2.01 Trees Farming Chemical Inputs (g/bushel), Product Input Energy (Btu/g), and WTT Energy Per Dry ton (Btu/dry ton) and Btu/mmBtu Anhydrous Ethanol

Chemical Type	Chemical Input (g/dry ton)	Product Input Energy (Btu/g)	WTT Energy (Btu/dry ton)	WTT Energy (Btu/mmBtu)
Nitrogen Fertilizer	709	45.3	32,125	4,676
Phosphate Fertilizer	189	12.9	2,444	356
Potash	331	7.9	2,612	380
Herbicide (average)	24	260	5,016	730
Insecticide (average)	2	307	606	88.2
Total				**6,409**

Note: Ethanol yield of farmed trees is assumed to be 90 gal/dry ton in CA-GREET.
WTT Energy is calculated as: WTT energy = chemical input (g/dry ton)* product input energy (Btu/g).

CA-GREET models nitrogen fertilizer as a weighted average of ammonia (70.7%), urea (21.1%) and ammonium nitrate (8.2%) fertilizer. As Table 2.01 shows, nitrogen fertilizer input accounts for more than 2/3 of total chemical energy input. The herbicide production energy is a weighted average of four types of herbicides used: atrazine (31.2%), metolachlor (28.1%), acetochlor (23.6%) and cyanazine (17.1%). The insecticide inputs represent an "average" insecticide, rather than an explicitly weighted average of specific insecticides. The energy required to produce nitrogen fertilizers, herbicides or pesticides does not vary significantly by category, attesting to the validity of using average energy inputs.

2.2 GHG Calculation for Production of Chemical Inputs

This component includes all of upstream emissions related to the manufacturing of agricultural chemical products. Upstream emissions are calculated in CA-GREET per ton of product, including the production, process and transportation emissions associated with manufacturing chemicals; these intermediate calculations take place in the *Ag Inputs* sheet of the model. These values are converted to emissions per ton of nutrient using the ratio of nutrient to product. At this level, nitrogen fertilizer greenhouse emissions are modeled as a weighted average of 3 types of N-fertilizers modeled in CA-GREET. Finally, energy and emissions are converted to Btu or grams greenhouse gases per g of nutrient (fertilizer) or product (herbicide and pesticide). At this point, average herbicide emissions are calculated using a weighted average of 4 herbicides and pesticide emissions are based on a single pesticide type. Table 2.02 below shows the greenhouse emissions for agricultural chemicals in grams per gram of nutrient for fertilizers and per gram of product for herbicides and pesticides. The formulas are complex and not shown here since agricultural inputs apply to large variety of crop cultivation and are not specific to trees cultivation.

Table 2.02 Calculated GHG Emissions (g/g) Associated with Production of Agricultural Chemicals

GHG Type	**Nitrogen (weighted average)**	**P_2O_5**	**K_2O**	**Herbicide (weighted average)**	**Pesticide**
	g/g nutrient			g/g product	
CH_4	0.0021	0.0014	0.0009	0.03	0.0337
N_2O	0.0016	<0.001	<0.001	<0.001	0.0002
CO_2	2.24	0.84	0.5	18	20.7
GHGs (g/g)	**2.9**	**1.02**	**0.69**	**21.5**	**25.0**

The greenhouse emissions of agricultural inputs are multiplied by chemical input factors (g/dry ton) in the *Ethanol* sheet and a loss factor from the *Ag Inputs* sheet to yield fertilizer emissions in grams per dry ton of farmed trees. Table 2.03 below shows the calculations for CO_2 emissions associated with the use of chemical inputs in g/dry ton of farmed trees produced. Table 2.04 details the values used in calculations in Table 2.03 These calculations exclude VOC and CO emissions converted to CO_2 (calculated in emission summary in CA-GREET). The formulas for CH_4 and N_2O are analogous to these calculations and are not shown. Table 2.05 shows the emission results for all greenhouse gases for chemical use, based on the calculations shown in Table 2.03.

Table 2.03 Calculated CO_2 Emissions Associated with Production of Agricultural Chemicals

Chemical Product	Formula	CO_2 Emissions		
		g/dry ton	g/mmBtu	g/CO_2e/MJ
Nitrogen (weighted average)	(A)*(B)*(C)	1,826	266	(266+23+24)/1055 = 312/1055 = 0.3
P_2O_5	(D)*(E)*(F)	159	23	
K_2O	(G)*(H)*(I)	166	24	
Herbicide	(M)* (N)*(O)	432	63	63/1055 = 0.06
Pesticide	(P)*(Q)*(R)	41.5	6	6/1055 = 0.006
Total CO_2 emissions		2,624	382	**0.42**

Table 2.04 Calculated CO_2 Emissions (g/g) Associated with Production of Agricultural Chemicals

Chemical Product	Relevant Parameters	Reference
A	Nitrogen input = 709 g/dry ton	CA-GREET default
B	Nitrogen chemical cycle emissions = 2.237 g/g	CA-GREET default
C	Nitrogen loss factor = 1.0	CA-GREET default
D	P_2O_5 input = 189 g/dry ton	CA-GREET default
E	P_2O_5 chemical cycle emissions = 0.8244 g/g	CA-GREET default
F	P_2O_5 loss factor = 1.0	CA-GREET default
G	K_2O input = 331 g/dry ton	CA-GREET default
H	K_2O chemical cycle emissions = 0.4926 g/g	CA-GREET default
I	K_2O loss factor = 1.0	CA-GREET default
M	Herbicide input = 24 g/dry ton	CA-GREET default
N	Herbicide chemical cycle emissions = 17.49 g/g	CA-GREET default
O	Herbicide loss factor = 1.0	CA-GREET default
P	Pesticide input = 2 g/dry ton	CA-GREET default
Q	Pesticide chemical cycle emissions = 20.16 g/g	CA-GREET default
R	Pesticide loss factor = 1.0	CA-GREET default

Note: Loss Factor occurs during transportation due to evaporation, venting, etc.

Table 2.05 shows the emission results (g/dry ton) for all GHG emissions for production of chemicals used in agriculture based on the calculations shown in Table 2.03. The CH_4 and N_2O emissions results shown in Table 2.05 are calculated with the same formula as CO_2 emission calculations, except, CO_2 emission factor is replaced by CH_4 and N_2O emission factors. Table 2.05 also shows the WTT emissions on an energy basis (g/mmBtu and g/MJ anhydrous ethanol).

Table 2.05 Calculated GHG Emissions from Production of Agricultural Chemicals

GHG Type	Nitrogen (weighted average)	P_2O_5	K_2O	Herbicide (weighted average)	Pesticide	Total
	g/dry ton			g/dry ton		
CH_4	1.48	0.27	0.29	0.53	0.06	
N_2O	1.15	0.002	0.002	0.003	<0.001	
CO_2	1,826	158	166	432	41.5	
GHGs (g/dry ton)	2,205	166	174	446	43	3,035
GHGs (g/mmBtu)	321	24.2	25.3	65	6.3	441.8
GHGs (g/MJ)	**0.3**	**0.03**	**0.03**	**0.06**	**0.01**	**0.46**

Note: To convert (g/dry ton) to (g/mmBtu):
(g/dry ton)/(Ethanol Yield (gal/ton) * LHV of Anhydrous Ethanol (Btu/gal))*10^6 .
E.g.: 2,205 (g/ton)/(90(gal/ton)*76,330 Btu/gal))*10^6 = 321 (g/mmBtu)

CA-GREET also calculates direct field and downstream N_2O emissions resulting from nitrogen fertilizer input. Table 2.06 below shows the two main inputs: fertilizer input (g/dry ton) and percent conversion of N-input to N_2O. This table shows the N_2O emissions on an energy basis (g/mmBtu and g/MJ anhydrous ethanol) and N_2O emissions associated with trees production are calculated the same way, using the relevant ethanol yield value (see note below Table 2.05). CA-GREET model assumes 1.3% of fertilizer-N is ultimately converted to N_2O. The calculation also uses the mass ratio of N_2O to N_2 (44/28). N_2 is used rather than N because two fixed N atoms are required for every N_2O molecule formed. As the Table 2.06 shows, soil N_2O are the dominant source of N_2O emissions and a significant component of net fuel cycle greenhouse gas emissions. The total GHG emissions for agricultural chemicals are detailed in Table 2.07.

Table 2.06 Inputs and Calculated Emissions for Soil N_2O from Trees Cultivation

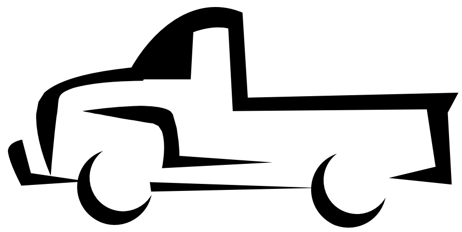
Fertilizer N input (g/dry ton)	Percent conversion to N_2O-N	N_2O formed/ N_2O-N (g/g)	N_2O Emissions (g/dry ton)	GHG Emissions (g/mmBtu)	GHG Emissions (g/MJ)
709	1.3%	(44/28)=1.57	14.5	628	**0.6**

Note: Soil N_2O emissions = (709 g N/ton)(1.3%)(44 g N_2O/28 g N_2) = 14.5 gN_2O/ton

Table 2.07 Total GHG Emissions for Agricultural Chemical Use for Farmed Trees Ethanol

Ethanol Pathway	Fertilizers	Herbicide	Pesticide	Soil N_2O	Total
GHGs (gCO_2e/MJ)	0.4	0.06	0.01	0.6	**1.1**

SECTION 3. FARMED TREES TRANSPORT



3.1 Energy for Farmed Trees Transportation

CA-GREET calculates the total energy needed (Btu/ton) to transport farmed trees from the field to the fuel production facility using heavy duty trucks. Table 3.01 below shows the farmed trees transportation distance and energy inputs. The calculations are based on heavy duty truck capacities 15 tons. The moisture content of the trees is assumed at 25% of the weight. The default distance transport distance 40 miles from the stack to the ethanol plant. CA-GREET calculates the diesel energy per ton mile based cargo capacity of the truck and its fuel economy and assumes that truck trips carrying farmed trees and returning empty use the same energy. All values are CA-GREET default values.

Table 3.01 Farmed Trees Transport Inputs

Transport Mode	Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	Capacity (tons)	Fuel Consumption (mi/gal)	Energy Consumption of Truck (Btu/mi)	Shares of Diesel Used
Field to Ethanol Plant Heavy Duty Truck	1,511	40	17	5	25,690	100%

The calculated farmed trees transport energy is shown below in Table 3.02 using the values in Table 3.01.

Table 3.02 Farmed Trees Transport Energy

Transport Mode	Energy Consumption (Btu/ton)	Energy Consumption (Btu/dry ton)
Field to Ethanol Plant by Heavy Duty Truck (with 25% tree moisture content)	148,936	148,936 Btu/ton/(1-25%) = 198,591
Total (anhydrous ethanol)		**28,907 (Btu/mmBtu)**

Note:

- For Heavy Duty Truck Transport Energy Consumption Calculation:

(40 miles one-way distance)*(1,511 Btu/ton-mile origin to destination + 1,511 Btu/ton-mile back-haul)*(Diesel share 100%)*(1+Diesel WTT Energy 0.232 Btu/Btu) = 148,936 Btu/ton (see table 1.06 for specific energy)

- Convert to Btu/mmBtu: 198,591 Btu/ton)/(90 gal/ton * 76,330 Btu/gal) * 10^6 = 28,907 Btu/mmBtu

3.2 GHG Calculations from Farmed Trees Transportation

GHG from farmed trees transportation are calculated from section 3.1 above with the same transportation mode, miles traveled, etc. as indicated by Table 3.01 above. Tables 3.03 detail key assumptions of calculating GHG from farmed trees transportation. All values used in calculations are CA-GREET default values.

Table 3.03 Key Assumptions in Calculating GHG Emissions from Farmed Trees Transportation Factors, all CA-GREET Default

Transport Mode	Energy Intensity (Btu/ton-mile)	Distance 1-way (mi)	CO_2 Emission Factors of Truck (g/mi)	CO_2 Emission Factors of Diesel used as transportation fuel (g/mmBtu)	CO_2 Emission Factors of Diesel Combustion (g/mmBtu)
Field to Ethanol Plant by Heavy Duty Truck	1,511	40	1,999	77,809 Origin to Destination	11,368
				77,912 Return Trip	

The calculated farmed trees transport energy on g/ton and dry ton of farmed trees basis, then converted to g/mmBtu is shown in Table 3.04 below.

Table 3.04 Farmed Trees Transport - CO_2 Emissions in g/mmBtu

Transport Mode	CO_2 Emission (g/ton)	CO_2 Emission (g/mmBtu)
Field to Ethanol Plant by Heavy Duty Truck	15,158	2,206
Total (gCO_2/MJ)		**2.1**

Note: Example formula to calculate CO_2 emission of Heavy Duty Truck above:

- For origin to destination and return:

((77,809 g/mmBtu diesel CO_2 EF for HDD truck+ 16,175 g/mmBtu diesel CO_2 EF)*100% diesel used)*1,511 (Btu/ton-mile) *40 miles/(10^6 mmBtu/Btu) = 5,684 g/ton

- Adjusted to 25% moisture content in the trees and both ways truck travel:

2* 5,684/(1-25%) = 15,158 g/ton

Similarly, CH_4, N_2O, VOC, and CO are calculated the same way (with different Emission Factor for each emission) and shown in Table 3.05. Then all emissions are converted to CO_2 equivalent based as shown in Tables 3.06.

Table 3.05 Farmed Trees Transport – Other GHG Emissions in g/mmBtu

Transport Mode	CH_4	N_2O	VOC	CO
Field to Ethanol Plant by Heavy Duty Truck	2.7	0.05	0.95	4.37

Note: Example formula to calculate CH_4 emission of Heavy Duty Truck above (using CH_4 Emission Factor):

- For Origin to Destination and return:

((1.524 g/mmBtu + 112.1 g/mmBtu)+100% diesel used)*1,511 (Btu/ton-mile) *40 miles/(10^6 mmBtu/Btu) = 6.86 g/ton

- Adjusted to 25% moisture content in the trees: (2*6.86)/(1-25%) = 18.3 g/ton
- Converted to g/mmBtu: [18.3 g/ton /(90 gal/ton * 76,330 Btu/gal)] * 10^6 = 2.7g/mmBtu

Table 3.06 Farmed Trees Transport – Converted to CO_2eTotal GHG Emissions

Transport Mode	CH_4 (gCO_2e/ mmBtu)	N_2O (gCO_2e/ mmBtu)	VOC and CO Conversion (g/mmBtu)	CO_2 (g/mmBtu)	GHG (gCO_2e/mmBtu)	GHG
Stack to Ethanol Plant Heavy Duty Truck	2.7*25 = 67.5	0.05*298 = 14.9	**VOC:** 0.95*0.85/0.27 = 2.99 **CO:** 3.84*0.43/0.27 = 6.95	2,106	2,198	**2.2**
Total GHG (gCO_2e/MJ)						**2.2**

SECTION 4. ETHANOL PRODUCTION

4.1 Ethanol Production by Fermentation

Ethanol production from farmed trees is via fermentation. Cellulose of the trees converted into ethanol through enzymatic process. The lignin portion of the trees that is not utilized by the enzymes can be burned to provide needed process energy. To calculate the ethanol production, CA-GREET uses energy input values for farmed trees ethanol in Btu/gallon of anhydrous ethanol and uses fuel shares to allocate this direct energy input to process fuels. The fuels used in the ethanol production process are diesel fuel for boilers, engines, and turbines and the energy embedded in the feedstock (farmed trees) itself. Table 4.01 below shows the ethanol production diesel shares and energy inputs per gallon of anhydrous ethanol. Co-generation systems can be employed to generate both steam and electricity from lignin of the trees for use on-site. Some amount of extra electricity can be generated in cellulosic plants and be exported to the electric grid. In the ethanol plant, 1.145 kWh/gal is credited as a CA-GREET default value. For this pathway in this document, credit is provided for both process energy and co-generated electricity. The average U.S. electric mix is used in the calculations.

Table 4.01 Farmed Trees Ethanol Primary Energy Inputs (Btu/gallon Anhydrous Ethanol)

	Fuel Share	**Primary Energy Input**
Conventional Diesel	<0.01%	389 Btu/gal
Farmed trees	100%	186,789 Btu/gal
Ethanol extracted credit from burning trees		-76,330 Btu/gal

By the default, the mass share of trees that is used for ethanol is 55%. The remaining part of the trees (45%) goes towards combustion for power and steam generation.

The CA-GREET model has not examined process simulation data for farmed trees to ethanol pathway and assumed here that this ratio should be lower than that for herbaceous biomass to ethanol pathway because of high lignin content of farmed trees.

CA-GREET uses the direct, primary energy inputs for ethanol production to calculate the total energy required to deliver each primary energy input. Tables 4.02 and 4.03 below show the CA-GREET equations, parameters and energy inputs for ethanol production. The tables show the total input energy per mmBtu of anhydrous ethanol and denatured ethanol (see Table 4.04 for greater detail about denaturant energy and emissions). Note that anhydrous ethanol is distilled ethanol (>99.6% purity). Ethanol is denatured with gasoline prior to transport to the bulk terminal for blending. The denaturant used in ethanol plants is typically natural gasoline, which is less expensive than reformulated gasoline and requires somewhat less energy to produce. The calculations here show the results for blending with CARBOB (2.5% by volume) and denatured ethanol is the finished ethanol product that is transported to bulk terminals for CaRFG production.

Table 4.02 Farmed Trees Ethanol Formulas, Parameters, and Total Energy

Fuel Type	Formula	Relevant Parameters	Total Energy (Btu/gal)
Diesel	CA-GREET Default	Direct diesel energy used in process	337
	Direct diesel energy *((Crude*Loss Factor) / 10^6 = (337Btu/gal * 105,677 Btu/mmBtu*1)/10^6	Energy upstream from crude (see Table 1.04)	35.6
	Direct diesel energy * WWT of diesel = (337 Btu/gal * 126,272 Btu/mmBtu*1)/10^6	Energy WTT of diesel	42.5
Farmed Trees	(1/90 tons/gal)*(LHV of trees 16,811,000 Btu/ton)	55% of farmed tree used as fuel: for 1 gallon of ethanol, 1/90 or 0.0111 tons of trees needed	186,789
		Ethanol energy extracted from trees	(-76,330)
Loss		Loss Factor in the process	1.0005
Total energy input for farmed trees ethanol production (Btu/gal)			110,874
Total energy input (Converted to Btu/mmBtu)		**110,874 Btu/gal*1.0005/76,330 Btu/gal *10^6**	1,453,295

4.2 Energy Credit from Co-generation of Electricity

In the tree ethanol plant, 1.145 kWh/gal is the amount electricity credited as a CA-GREET default value. Co-generation systems can be employed to generate both steam and electricity from lignin of the trees for use on-site. Some amount of extra electricity can be generated in cellulosic plants and be exported to the electric grid as show in table 4.04.

Table 4.03 Energy Credit from Co-generation System

Parameter	Formula	Calculations*	Values (Btu/gal)
Credit from Co-generation	CA-GREET default	1.145 kWh/gal *3,412 Btu/kWh = 3,907 Btu/gal	
Upstream electricity generation as feedstock (see Table 1.04)	Electricity as feedstock * credit	103,008 Btu/mmBtu*(-3,907 Btu/gal)/10^6	-402
Upstream electricity generation as fuel	Electricity as fuel * credit	2,173,222 Btu/mmBtu*(-3,907 Btu/gal)/10^6	-8,490
Transmission loss	CA-GREET default of transmission loss * credit * (electricity as feedstock + as fuel)/ 10^6	-8.1% (-3,907 Btu/gal) *(103,008+2,173,222)/10^6	720.3
Loss Factor of the system	CA-GREET default	1.0005	
Total Credit (Btu/gal) = -(402+8,490-720.3)*1.0005			-8,172
Co-generation Credit Convert to Btu/mmBtu (as ethanol)			**-107,120**

Note: See Table 1.04 for WTT of Energy

4.3 GHG Emissions from Ethanol Production by Fermentation

GHG from ethanol production is calculated based on the assumptions in Table 4.03 below and the results are shown in Table 4.05. As indicated in the previous section, the majority of direct energy used is from trees burning (99.9%), plus a small amount of diesel used in the process. These shares of energy are multiplied with the GHG emission factors of equipments used.

Table 4.04 Process Shares and Emission Factors (EF) of Ethanol Production Equipment by CA-GREET Default

EtOH Production Equipment and Fuel Used	% Shares of Equip. Usage	CO_2 EF (g/mmBtu of fuel burned)	VOC EF	CO EF	CH_4 EF	N_2O EF	Assumed % of Fuels used	Direct Energy Use (Btu/gal)
large industrial boiler	33%	78,167	1.17	16.69	0.18	0.19	0.1%	337*1.0005 = 337.2
stationary engine	33%	77,401	70.44	361	3.9	2		
diesel turbine	34%	78,179	1.33	8.71	0.84	2		
farmed trees small boiler	100%	102,241	5.34	76.8	3.83	11	99.9%	186,789* 1.0005 = 186,882.4
Total Energy Used (after applied loss factor) (Btu/gal)								**187,220**

Table 4.05 Calculated CO_2 Emissions (g/gal Denatured) for Farmed Trees Ethanol Production Using CO_2 Factors from Table 4.05

	Calculations CO_2 in g/gal		Conversion to CO_2 (g/mmBtu)	Results
From Diesel combustion				
large industrial boiler	$337.2*33\%*78,167/10^6$ = 8.7	26.3	(26.3 g/gal)/(76,330 Btu/gal)*10^6	344
stationary engine	$337.2*33\%*77,401/10^6$ = 8.6			
diesel turbine	$337.2*34\%*78,179/10^6$ = 9			
WTT diesel	337.2* (2,899*1+8,987) /10^6 = 4 (see table 1.06 for diesel WTT)	4	(4 g/gal)/(76,330 Btu/gal)*10^6	52.5
From Trees Energy				
farmed trees small boiler	186,882.4*100%*102,224/ 10^6	19,104	(19,104 g/gal)/(76,330 Btu/gal)*10^6	250,197
Ethanol Extracted from Farmed Trees				
CO_2 credit from extracted ethanol	16,811,000*102,241/106* (1/90)*(100%-55%)*1.0005	-8,606	-8,606/76,330 Btu/gal*10^6	-137,608
Total GHGs (gCO_2e/mmBtu)				**113,042**

Note: Feed Loss Factor is assumed at 1.0005

Table 4.06 Calculated CO_2 Equivalent Emissions (g/gal Denatured) for Farmed Trees Ethanol Production Using GHG Emission Factors from Table 4.05

VOC	Calculations CO_2 in g/gal		Conversion to CO_2 (g/mmBtu)	Results
large industrial boiler	(Direct energy use of diesel)* VOC EF = 337.2*33%*(1.17)/10^6	<0.01	(0.01 g/gal)*(0.85/0.27)/77,254*10^6 *1.0005	0.01
stationary engine	(Direct energy use of diesel)* VOC EF = 337.2*33%*(70.44)/10^6	0.01	(0.01 g/gal)*(0.85/0.27)/77,254*10^6 *1.0005	0.01
diesel turbine	(Direct energy use of diesel)* VOC EF = 337.2*33%*(1.33)/10^6	<0.01	0.01 g/gal)*(0.85/0.27)/77,254*10^6*1.005	0.01
farmed trees boiler	(Direct energy use of diesel)* VOC EF = 337.2*33%*(5.34)/10^6	<0.01	(0.01 g/gal)*(0.85/0.27)/77,254*10^6*1.005	0.01

Similar calculations for CO, CH_4, and N_2O, the values are small and insignificant as shown in the Table 4.07 below. Therefore, the total GHG (in CO_2e/MJ) for farmed trees ethanol by fermentation is estimated at 109.5 CO_2e/MJ (anhydrous)

Table 4.07. GHG Emissions for Ethanol Production by Fermentation

GHG Species	GHG Emissions
VOC	6
CO	85.3
CH_4	11.56
N_2O	6.85
CO_2	113,042
Total GHGs (gCO_2e/mmBtu Anhydrous)	115, 527
Total GHGs (gCO_2e/MJ) (Anhydrous)	**109.5**

(See Table 4.08)

Table 4.08 is showing the GHG credit from burning trees that is used in the ethanol plant. The amount of CO2 is in burnt trees that is from the atmosphere.

Table 4.08. GHG Emission Credits from Burning Trees as Fuel in Cellulosic Ethanol Plant

Emissions	
CO_2 (g/gal)	-8,606
CO_2 (gCO_2e/mmBtu)	-112,808
GHG (gCO_2e/MJ)	**-106.9**

Note: trees burning credit is calculated as following:
(1/(90 gal/dry ton)) *(1-55%)*51.7% C ratio*(2000 lb/dry ton)*(454 g/lb)*(44 of CO_2)/(12 of C))*loss factor
Where:

- ethanol from tree yield: 90 gal/dry ton
- 55% is the mass of tree go into making ethanol
- (1-45%) is the mass of trees to make power and steam in the process
- loss factor is 1.0005

GHGs also are credited in the co-geneneration system as shown in table 4.10 below

Table 4.09. GHG Emission Credits from Co-Generation Electricity in Cellulosic Ethanol Plant

Emissions	**g/gal**	**g/mmBtu**
CH_4 (g/gal)	-0.967	-12.3
N_2O (g/gal)	-0.008	-0.1
CO_2 (g/gal)	-462	-6,051
GHG (gCO_2e/mmBtu)		-6,388
GHG (gCO_2e/MJ)		**-6.06**

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SECTION 5. ETHANOL TRANSPORT AND DISTRIBUTION

5.1 Energy for Ethanol Transportation and Distribution

Transport from the ethanol plant to the bulk terminal or storage facility is accomplished primarily by rail (with short truck delivery to terminal or storage facility). The transport distance based on AB1007 analysis is 1,400 miles by rail and 40 miles by truck. The local distribution step involves transporting ethanol to a gasoline blending terminal where it is blended with gasoline to produce CaRFG. The estimated distribution distance is 50 miles based on the AB1007 analysis.

Instead of calculating the WTT values on a per ton basis as CA-GREET does for the farmed trees transport component, CA-GREET calculates WTT energy required per mmBtu of fuel (anhydrous ethanol) transported. Table 5.01 below shows the major inputs used in calculating transport energy and Table 5.02 presents the CA-GREET formulas used to calculate the ethanol transport energy for each transport mode.

Table 5.01 Inputs and Calculated Fuel Cycle Energy Requirements for Ethanol Transport to Bulk Terminals

Transport	Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	Capacity (tons)	Fuel Used (mi/gal)	Energy Used of Truck (Btu/mi)	Shares of Diesel Used	% Fuel Transported by Mode
Transportation by Rail	370	1,400	n/a	n/a	n/a	100%	100%
Distribution by HDD Truck	1,028	30	25	5.0	25,690	100%	100%

Table 5.02 CA-GREET Calculations for Ethanol Transport Energy (Btu/mmBtu Anhydrous Ethanol) by Transport Mode

Transport Mode	CA-GREET Formula	Relevant Parameters	Btu/mmBtu
Transport By Rail	10^6/(76330)*(2988)/((g/lb)*(lb/ton)*(1400)*(370)*((100%)*(1+0.232))	Ethanol LHV = 76,330 Btu/gal Ethanol density = 2,988 g/gal Miles traveled = 1,400 Diesel energy intensity of rail = 370 Btu/ton-mile Diesel shares = 100% Diesel energy as transportation fuel = 0.232	27,512
Distribution By Truck	(10^6)/(76330)*(B)/((g/lb)*(lb/ton)*(30)*2*(1028)*((100%)*(1+0.232))*80%	Miles traveled = 30 G = Diesel energy intensity of truck = 1,028 Btu/ton-mile H = 80% distribution by truck (20% assumed directly by pipeline)	2,620
T&D Total (Btu/mmBtu)			**30,132**

Note: The energy intensity for heavy duty trucks is multiplied by 2 to account for return trip.

5.2 GHG Calculations from Ethanol Transportation and Distribution

Similar to Farmed trees T&D, ethanol T&D to bulk terminal is assumed in CA-GREET model by rail carts and then to destination by truck. All the key assumptions are the same as Farmed trees T&D's and are shown in Table 5.03.

Table 5.03 Key Assumptions in Calculating GHG Emissions from EtOH Transportation

Transport Mode	1-way Energy Intensity (Btu/ton-mile)	Distance from Origin to Destination (mi)	CO_2 Emission Factors (g/mi)	CO_2 Emission Factors of Diesel used as transportation fuel (g/mmBtu)	CO_2 Emission Factors of Diesel Combustion (g/mmBtu)
100% Rail	370	1,400		13,900	77,664
100% Heavy Duty Truck	1,028	30	1,999	13,900	77,912

Note: Assumed all locomotives use diesel

The results are shown below in Table 5.04. The WTT emissions shown in the Table for each GHG species is calculated in the *T&D* tab of CA-GREET. The equation for CO_2 from rail is shown below and the calculations for the other transport modes and GHG gases are done similarly. Note that only one-way rail emissions are counted, whereas an extra term exists in the calculation for truck transport to account for the return truck trip; emissions from the return trip are assumed to be equal to emissions for the trip from the origin to destination.

Rail CO_2 emissions = (Ethanol density 2,988 g/gal)/(Ethanol LHV 76,330 Btu/gal)/[(454 g/lb)*(2,000 lbs/ton)]*[(Diesel emission factor 77,664 g/Btu)+(Diesel WTT emissions 11,187 g/mmBtu)]*(370 Btu/ton-mile)*(1400 miles) = 2,096 g/mmBtu anyhydrous ethanol.

Truck CO_2 emissions are calculated the same way with its own emission factors:

Truck CO_2 emissions = (Ethanol density 2,988 g/gal)/(Ethanol LHV 76,330 Btu/gal)/[(454 g/lb)*(2,000 lbs/ton)]*[(Diesel emission factor from origin 77,809 g/Btu)+2(Diesel WTT emissions 11,187 g/mmBtu)+ (Diesel Emission actor from destination 77,912 g/Btu)]*(1,028 Btu/ton-mile)*(30 miles) = 250 g/mmBtu anhydrous ethanol.

Table 5.04 EtOH Transport – GHGs Emissions in g CO_2e /mmBtu

Transport Mode	**CO_2 Emission**	**CH_4 to CO_2e**		**N_2O to CO_2e**		**CO_2e (g/mmBtu)**
Transported by Rail	2,096	2.59	64.8	0.05	14.7	2,189
Distributed by Heavy Duty Truck	250	0.24	7.7	0.005	1.75	249
Total	2,346		70.8		16.4	2,449
Total (gCO_2e/MJ)						**2.3**

SECTION 6. EMISSIONS FROM ETHANOL COMBUSTION

6.1 GHG Calculations from Ethanol Combustion

Anhydrous ethanol is not used in CA directly as a fuel. It is blended with a denaturant before it is shipped from a production plant. The use of 10% by volume (nominal) of ethanol in CaRFG is detailed in the CaRFG pathway. Since CO_2 released from the combustion of ethanol was essentially 'fixed' by the plant during its growth, CO_2 emissions from combustion of ethanol derived from farmed trees is considered carbon-neutral. Attendant CH_4 and N_2O emissions when used in CaRFG is detailed in the CaRFG pathway.

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APPENDIX B
ETHANOL PATHWAY INPUT VALUES
(FROM FARMED TREES)

Scenario: Ethanol made by farmed trees by fermentation outside of California and transported to California to blend with California Gasoline

Parameters	Units	Values	Note
GHG Equivalent			
CO_2		1	
CH_4		23	
N_2O		296	
VOC		3.1	
CO		1.6	
Farmed Trees Farming			
Fuel Use Shares			
Diesel		94.3%	
Electricity		5.7%	
Cultivation Equipment Shares			
Diesel Farming Tractor		80%	
CO_2 Emission Factor	g/mmBtu	77,204	
Diesel Engine		20%	
CO_2 Emission Factor	g/mmBtu	77,401	
Farmed trees Farming			
Farmed trees energy use	Btu/bu	234,770	
Land Use CO_2 Emission from trees farming	g/dry ton	112,500	
Farmed trees T&D			
Transported from trees field to EtOH plant			
by heavy duty diesel truck	miles	40	1,713 Btu/mile-ton Energy Intensity
fuel consumption	mi/gal	5	capacity 15 tons/trip
CO_2 emission factor	g/mi	1,999	
Chemicals Inputs			
Nitrogen	g/dry ton	709	
NH3			
Parameters	**Units**	**Values**	**Note**
Production Efficiency		82.4%	
Shares in Nitrogen Production		70.7%	
CO_2 Emission Factor	g/g	2.475	
Urea			
Production Efficiency		46.7%	
Shares in Nitrogen Production		21.1%	
Ammonium Nitrate			
Production Efficiency		35%	
Shares in Nitrogen Production		8%	
P_2O_5	g/dry ton	189	
H_3PO_4			
Feedstock input	tons	n/a	
H_2SO_4			
Feedstock input	tons	2.674	
Phosphor Rock			
Feedstock input	tons	3.525	
K_2O	g/dry ton	331	
Herbicide	g/dry ton	24	
Pesticide	g/dry ton	2	

EtOH Production			
EtOH Yield	gal/dry ton	90	
Energy use		45,970	
Diesel Use		0.1%	
Commercial Boiler	g CO_2/mmBtu	78,167	33% usage
Diesel Engine	g CO_2/mmBtu	77,401	33% usage
Diesel Turbine	g CO_2/mmBtu	78,179	34% usage
Farmed trees used as fuel		99.9%	45% of farmed trees used as fuel
Boiler	g CO_2/mmBtu	102,241	
EtOH T&D			
Transported by rail	miles	1,400	370 Btu/mile-ton Energy Intensity
Transported by HHD truck	miles	40	1,028 Btu/mile-ton Energy Intensity both ways
Distributed by HHD truck	miles	30	1,028 Btu/mile-ton Energy Intensity both ways
Fuels Properties	**LHV (Btu/gal)**	**Density (g/gal)**	
Crude	129,670	3,205	
Residual Oil	140,353	3,752	
Conventional Diesel	128,450	3,167	
Conventional Gasoline	116,090	2,819	
CaRFG	111,289	2,828	
CARBOB	113,300	2,767	
Natural Gas	83,868	2,651	As liquid
EtOH	76,330	2,988	Anhydrous ethanol
EtOH	77,254	2,983	Denatured ethanol
Still Gas	128,590		
Farmed Trees	16,811,000	n/a	Btu/dry ton